

1.0 Statement of Work for FY '94

1.1 This document describes Lockheed Sanders' overall goals for the NRA effort "Rapid Design Process to Shuttle Reaction Jet Amplifier" (contract no. NAS 9-18873), specific goals of the FY '94 NRA, and the actual tasks that will be performed to achieve these goals. Where appropriate, future tasks which will be required to meet the ultimate goals are identified. An estimate of required level of effort and a schedule for this work will be provided. P. 5

2.0 Goals of the NRA effort

2.1 This NRA effort is devoted to developing new techniques and methodologies which utilize and/or provide support to Integrated Vehicle Health Management (IVHM) concepts and techniques, modern design processes and open architectures to realize:

- An Avionics system architecture that relieves the Flight Control System (FCS) of the requirement of maintaining intimate knowledge and control of the vehicle subsystems (for instance, the Reaction Control System (RCS)). The benefit of this architecture is that future upgrades and enhancements to the system(s) or to individual components within the system(s) are greatly simplified. This approach also allows a much more straightforward treatment of failure analysis, system diagnosis, and the design of fault containment domains.
 - Capabilities to provide an available avionics system (and subsystem(s)) at minimum operational cost. This thrust provides a direct benefit to NASA in that it seeks to accelerate the design cycle to allow state of the art components and designs to actually appear in the fielded system rather than merely in the initial design. To achieve this, this effort is intended to benefit from efforts already underway at Lockheed and other major contractors. For instance, Lockheed Sanders is currently engaged in a major DoD funded development program which has the goal of cutting design cycle time of high performance electronics by a factor of four while simultaneously improving quality also by a factor of four. The early work on this program was used to enable the rapid prototyping of the Reaction Jet Drive Controller which was accomplished in 1993. Similarly, maximum leverage will be derived from recent NASA and DoD efforts to increase the content of high quality commercial grade electronic components in systems for aerospace applications. Both of these goals result in a system with enhanced cost effectiveness, increased reliability, and greatly increased performance compared to a system developed using a more conventional approach.
- 2.2 The NRA will use the design and fabrication of a Reaction Control System jet driver assembly as a test case to work the newly developed paradigms. Potential target platforms under

active investigation include updates, retrofits and new vehicles such as:

- ATLAS and Delta expendable launch vehicles
- Shuttle
- Single Stage To Orbit (SSTO) vehicles
- Commercial and Military Satellites
- Transfer vehicles

2.3

For FY '94, this NRA will focus on three tasks, described in further detail in the following sections of this Statement of Work:

- The development of Integrated Vehicle Health Management (IVHM) requirements.
- The "productization" of the prototype Reaction Jet Driver (RJD) controller that was developed during 1993.
- The investigation into methods of predicting the impending End of Useful Life (EOUL) of thruster fuel and oxidizer control solenoids and other electromechanical equipment and devices.

As mentioned previously, these tasks represent elaborations on and further development of tasks begun during 1993.

3.0 System Concept for Integrated Vehicle Health Management (IVHM)

The preceding work on defining IVHM strategies have all focused on the need to incorporate design for IVHM at the earliest stages of a system's evolution. In addition to incorporating IVHM concepts into a system concept early in the design cycle, it is important to design in a top down fashion. Therefore, this effort will develop an extensible system level architecture concept. From these concepts, a set of consistent subsystem requirements will be developed. Finally, some of these concepts will be demonstrated, and their performance analyzed, using the prototype RJD controller built during FY '93.

3.1 The aim of developing a system level architectural concept is to design an avionics system which is capable of meeting overall system level availability and fault tolerance requirements. For instance, if an engine were to be shut down, the avionics should be able to respond in such a fashion, perhaps by changing the thrust angles of the remaining engines, to enable the vehicle to still achieve its mission. In order to develop such a top level system architecture for Vehicle Health Management it will be necessary to coordinate among the various suppliers and architects of such a system. Therefore, a key portion of this task will involve meetings and interchanges with other airframe manufacturers and avionics vendors, such as Honeywell and Martin

Marietta, and other design resources such as NASA/Ames to reach a consensus architecture which addresses these high level requirements.

To validate that this architecture can, in fact, be built and that it will perform as designed, a subtask, which will not be funded under this effort, but, is a candidate for Lockheed internal funding, is to model the architecture performance using a commercially available architecture simulation tool like Opnet (from MIL-3) or Bones (from Comdisco).

3.2 During FY '93, this NRA demonstrated some of the fundamental requirements of a design that addresses Vehicle Health Management principles at the subsystem (in this case, the RCS subsystem) level. These requirements include:

- The elimination of single points of failure (i.e., thruster fail-on and fail-off).
- The incorporation of instrumentation necessary to detect the occurrence of faults.
- The development of logic to respond to failure conditions at the subsystem level.
- Provisions for predictive analysis of sensor data to allow for the adaptation to changing environments.

During FY '94, an effort will be undertaken to develop the requirements for Health Management at the next higher Subsystem Level, which, in the case of the archetypical RCS subsystem, is represented by the entire Vehicle Management System.

The result of this task will be a report.

3.3

To demonstrate the implications of integrating Vehicle Health Management at a component level, the RJD prototype controller will be integrated into the Controls development Laboratory (CDL) and the JSC Avionics Engineering Laboratory (JAEL) at NASA/JSC. Performance while interfaced with "standard" configurations will be demonstrated. Error conditions will be introduced and the limits of the built in fault detection, isolation, and recovery will be explored.

This effort will be a joint collaboration requiring the support of NASA/JSC, Lockheed Engineering & Sciences Company, and Lockheed Sanders personnel.

4.0 Productization of the RJD Controller

During 1993, a prototype of a fault tolerant Reaction Jet Drive Controller which incorporates a demonstration of IVHM principles was designed and fabricated. During 1994, the prototype will be re-designed to incorporate lessons learned from the exercising of the prototype in the NASA/JSC JAEL and to provide for a redundant

digital control and status interface. This new design will be repackaged into a form factor that conforms to the requirements imposed by the launch vehicle environment. The RJD controller will then be subjected to thermal, vibration, and vacuum testing to verify that the controller is capable of controlling a Reaction Jet on a launch vehicle.

Specific attention will be dedicated to exploring the costs and benefits of modularizing the design, for example allowing common building block elements to be assembled to control the desired number of thrusters. As a part of this effort, a study will be made of the redundancy and robustness gains that may accrue from such an approach.

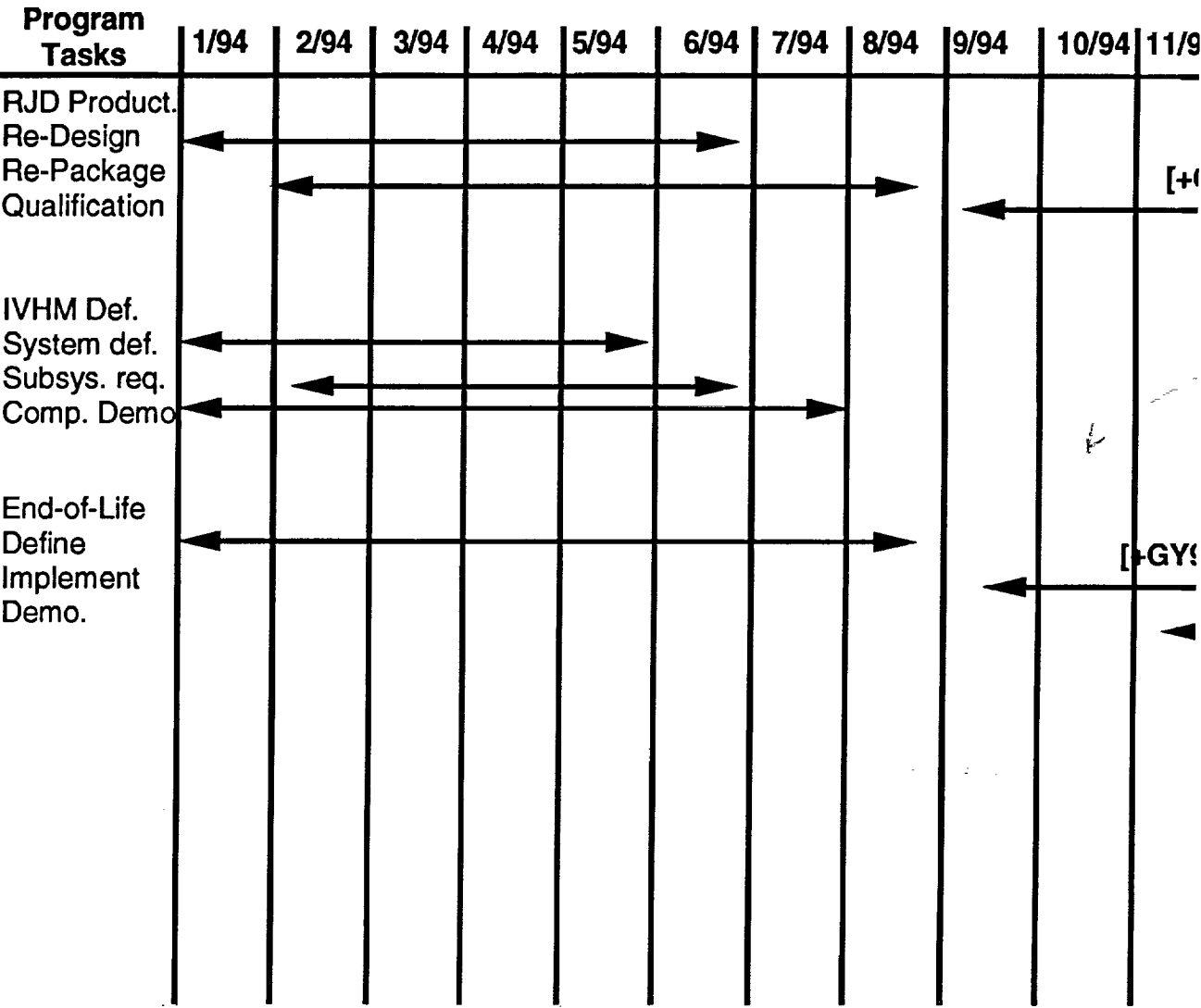
5.0 Investigating the End Of Useful Life of Solenoids

During 1993, it was noted that the impending End Of Useful Life (EOUL) of the solenoids which drive the valves of the Reaction Control System (and control Main Propulsion System valves as well as elements of other subsystems) can be predicted by examining a plot of the rise time of the turn-on current for the given solenoid. Unfortunately, this phenomenology has yet to be mathematically characterized. During FY '94, Government furnished data will be analyzed to derive some mathematical justification for classifying a given rise time curve as either predicting trouble free operation or impending failure. This reasoning will then be captured in an algorithm which will be implemented and demonstrated on the prototype equipment installed in the NASA/JSC JAEL.

Having arrived at a suitable candidate residual life estimation algorithm, we will then perform an assessment of the hardware that would best host the algorithm. Conventional microprocessor, digital signal processor (DSP), and Application Specific Integrated Circuit (ASIC) approaches will be examined. Pending a cost/performance trade, an approach will be selected and a demonstration system integrated and delivered as part of this effort.

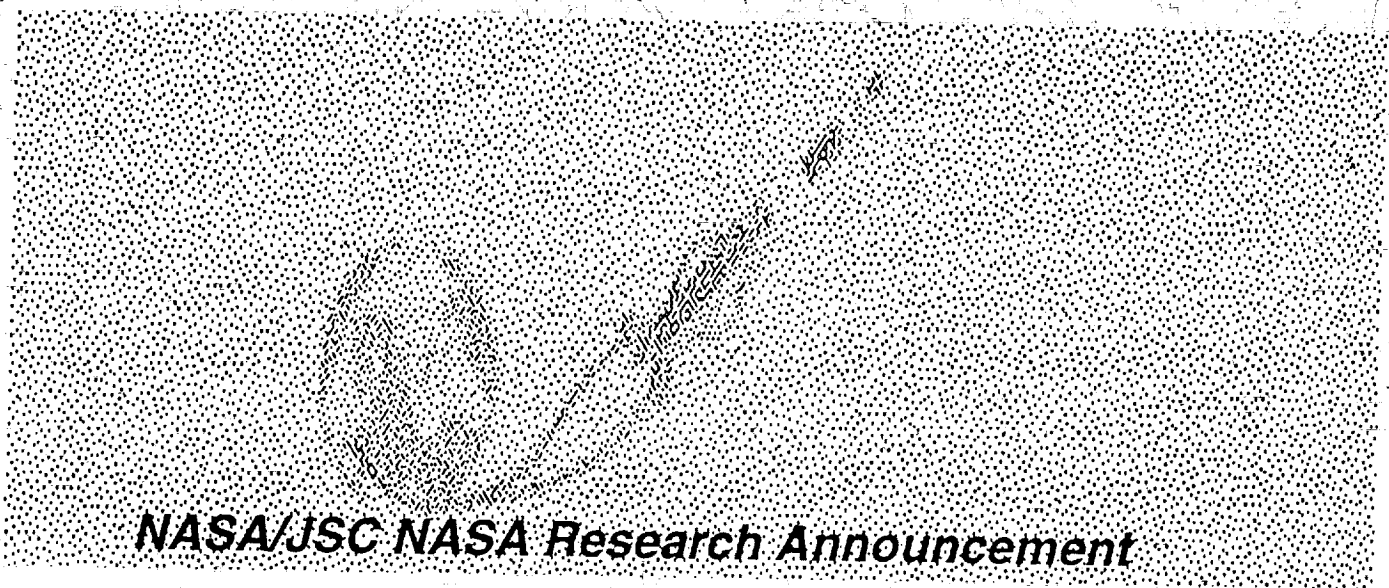
As noted, the successful completion of this task is dependent on the active cooperation and participation of NASA/JSC personnel and, potentially, vendors of solenoids.

6.0 Proposed Project Timeline





Lockheed Sanders



NASA/JSC NASA Research Announcement

APPENDIX B

Rapid Development Approaches for
System Engineering and Design

Interim Technical Report
July 1993